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Research article

Social choice functions: A tool for ranking variables involved in action plans against road noise

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ABSTRACT

Traffic noise is gaining importance in planning and operation of roads in developing countries, and particularly in Europe and Latin America. Many variables with different degrees of importance influence the perception of noise from roads. Thus, the problem of prioritizing road stretches for action against such noise is an important issue in environmental noise management. For example, it can be addressed using multicriteria methods. However, these methodologies require criteria or suitable variables to be ranked according to their relative importance. In the present study, for this ranking, a list of nine variables involved in the decision-making process (called "road stretch priority variables") was presented in the form of questionnaires to high-level experts from Andalusia, southern Spain. These experts ranked the variables by relevance. Using the same data, seven social choice functions (Plurality, Raynaud, Kemeny-Young, Copeland, Simpson, Schulze, and Borda) were used in order to rank the variables. The results indicate that the most important variables were those that take into account the parameters of greatest exposure for the citizens, followed by variables related to the intensity of the problem analyzed. The results show that a combination of the use of social choice functions on aggregated information from expert panels can provide a consensus for ranking priority variables related to road stretches.

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1. Introduction

In recent years, the density of road networks has rapidly increased in developing and developed countries and design parameters have improved. This development has been accompanied by progressively denser and faster traffic.

The primary objective of road administrations worldwide is a road network that connects different points of a territory, that satisfies transportation needs, and that can be maintained in an adequate state of conservation (Manaugh et al., 2015). However, this approach is significantly changing in developed countries in that users (and, ultimately, society) are beginning to require a high level of quality of the road services, in addition to providing a connecting path between destinations (Ruotolo et al., 2013; Tochtermann, 2001). This increasing demand also involves consequences for the environment (Demirel et al., 2008; Madireddy et al., 2011). Traffic noise is considered one of the major causes of environmental degradation in urban environments (Öhrström et al., 2006; Sato et al., 1999). Road traffic noise must be taken into account as an important factor in the planning of transport and its infrastructure within a global environmental management. Also, large populated areas already exposed to traffic noise need measures to reduce the problem. Therefore, the current legislation in the European Union requires administrations responsible for road networks to study and analyze road stretches that have excessive traffic noise levels affecting nearby populations (European Union, 2002; King et al., 2011). Consequently, the initial step in the formulation of a Noise Action Plan is the identification and sorting of these so-called "hot spots" by priority. This arises as an important issue for environmental managers (Licitra et al., 2011).

In this context, a well-defined decision-making process is

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needed to reach an efficient and well-justified sorting for these problematic road stretches (Cafiso et al., 2002; Chan, 2002; Choocharukul, 2004; Herbsman et al., 1995). As in most decision problems, several criteria are involved in the planning process, requiring a discrete multicriteria analysis. Thus, it is important to adequately assess the variables that take part in the sorting process studied, from the point of view of both noise exposure, and road characteristics and traffic (Filho et al., 2004). However, this process is not obvious, since variables used in sorting road stretches by priority for action have different degrees of importance. Moreover, these are initially unknown to the planners or difficult to define. An important issue thus arises, i.e., establishing the relative influence of the variables to perform an adequate decision-making.

Therefore, in the present study, the opinions of experts were compiled by the expert panel technique (EPT). Numerous studies using EPT can be found in all areas of knowledge, particularly in medicine, psychology, and other social sciences as well as in environmental and engineering fields (Beecham et al., 2005; Carpio et al., 2015; Wang et al., 2008; Mahboubi et al., 2015; Varho et al., 2013; Zhang and Huang, 2011). The use of expert panels enables decisions to be confirmed in the light of existing experience in the topic of study when empirical testing is not feasible. However, the results should maintain objectivity and rigor, making it necessary for the information collected to be submitted to aggregation techniques in order to generate a single decision.

This paper seeks to estimate the order of importance for the variables influencing the decision problem of prioritizing road stretches in a Noise Action Plan and to introduce the results for hotspot sorting. The main objective is to propose an easy and comprehensive method to rank the variables involved in an automated and consistent manner. In this method, data is gathered from responses of a panel of experts, who selected and compared the relative importance of the variables involved in the problem of prioritizing actions against road traffic noise. For this, several social choice functions (SCF) were applied to the various orderings determined by each expert to establish an average consensus ranking. Therefore, improvements in the decision-making methodology based on these ranked variables (called "road stretch priority variables") can be then proposed. Additionally, a calibration test was achieved in the Spanish context.

The "Road Stretch Priority Variables" (RSPV) were identified in a previous work (Ruiz-Padillo et al., 2014), providing a starting point to the present study. These are briefly presented in Section 2 for the sake of completeness. Then, Section 3 (Methodology) shows both the expert panel technique used to compile the data necessary for the study, and the social choice functions employed in this work. Also, some references and practical indications are given, which related to the implementation of these SCF (programmed in R software and Python library). In Section 4, the results of the methodology used are presented and critically discussed, considering the consistency of the results and the meaning of the variables. Finally, Section 5 highlights the main conclusions drawn in this research, i.e., the possibility of applying SCF with some changes for this problem and the consistency and applicability of the results.

2. Road stretch priority variables

RSPV are variables used by the planners as criteria for prioritizing the road stretches included in a Noise Action Plan. They were determined and defined in Ruiz-Padillo et al. (2014), and are used here with some refinements taking into account the previous experience. These variables are as follows:

- Stretch traffic data: in this category the intensity of vehicles (average daily traffic – *ADT*) and the percentage of heavy vehicles (*%hv*) are considered. In addition to Ruiz-Padillo et al. (2014), the average speed of the vehicles in the stretch (*s*) is now added, since it also bears influence on the generation and reduction of noise, as is in noise mapping (Naish, 2010; Ouis, 2001).
- Complaints about traffic noise produced in a particular road stretch, if existing, would be covered in the variable E_C (taking on a binary indicator, either "yes" or "no").
- The RSPV noise level of necessary attenuation (ΔL) is obtained from the difference between the existing sound level and the acoustic quality objective, in view of the corresponding noise zoning of the stretch studied under the current legislation (European Union, 2002; King et al., 2011). The noise levels indicators are calculated from the day-evening-night noise indicator weighted for overall annoyance (L_{den}), as in Eq. (1), where L_{day}, $L_{evening}$ and L_{night} are the A-weighted long-term average sound level determined over all the day, evening and night periods of a year, respectively (7:00–19:00, 19:00–23:00 and 23:00–7:00).

$$L_{den} = 10\log\left(\frac{12\cdot 10^{\frac{L_{day}}{10}} + 4\cdot 10^{\frac{L_{evening}+5}{10}} + 8\cdot 10^{\frac{L_{night}+10}{10}}}{24}\right) \quad (1)$$

- Exposed surface (S_{exp}) and exposed population (P_{exp}) to excessive noise level (i.e. sound levels above legislation limits in terms of L_{den} descriptor).
- Noise sensitive centers. In Ruiz-Padillo et al. (2014) this is considered as a binary variable (E_{SC}) taking into account its importance in the acoustic quality objectives for determining noise zoning (European Union, 2002). However, sensitive centers exposed to high levels of noise must be taken into account not only with the regard of its mere existence. Therefore, the formulation of this variable was adapted to count the number of exposed noise sensitive centers (SC_{exp}) just as the previous variables.
- Finally, the existence of anti-noise measures —both previously established and planned— was still considered in the binary variable E_{ANM}.

The nine RSPV are summarized in Table 1.

3. Methodology

An expert panel was generated through surveys, where participants were asked to sort the RSPV by the criterion of the relative importance of each variable in the decision-making problem of sorting road stretches by priority for action against road traffic noise. Because every SCF employs various logic principles and algorithms, a set of SCF was used to reach different ordered lists of the RSPV. Then, they were compared to define a more

Table 1
List of road stretch priority variables.

No.	Road stretch priority variables	
1	ΔL	Noise level of necessary attenuation
2	P_{exp}	Exposed population
3	S_{exp}	Exposed surface
4	*ADT*	Average daily traffic
5	*%hv*	Percentage of heavy vehicles
6	*s*	Average speed of vehicles
7	E_C	Occurrence of citizens' traffic noise complaints
8	SC_{exp}	Exposed noise-sensitive centers
9	E_{ANM}	Existence of previous measures of acoustic attenuation

representative consensus ranking, supported by the combination of both EPT and SCF techniques.

This approach has been widely used in the literature, not only in social and economic studies (Alcantud et al., 2013; Gabel and Shipan, 2004; Serrano et al., 2014) but also in engineering and environmental fields (d'Angelo et al., 1998; Srdjevic, 2007). However, this method has not been previously used in road traffic noise and its management as an environmental impact.

3.1. Expert panel technique

The EPT is widely used as support for decision-making procedures, allowing experts to participate in the collective decision-making with their experience and knowledge. A group decision is generated, this normally being more accurate than the decision made by individual members. In this process, experts independently and anonymously express their judgments by filling out a questionnaire (Gabel and Shipan, 2004).

The definition of the profile of the experts is essential, as they must be knowledgeable and experienced regarding the decision-making problem at hand (Beecham et al., 2005; Gambatese et al., 2008). In addition, experts must be chosen from the most competent available while ensuring their heterogeneity. Thus, groups with different opinions, approaches or knowledge about the topic are sought (Gabel and Shipan, 2004; Mahboubi et al., 2015). Moreover, the reliability of a judgment is believed to increase with the number of members (Gambatese et al., 2008). The recommended number according to Turoff (1970) is between 10 and 50 participants.

In the case of establishing priorities of actions on road stretches with noisy road traffic, decisions correspond only to high levels of the public administrations responsible for road networks. Besides, representatives of different administrative levels and different geographical areas should also be part of the expert panel. The procedure of selecting experts for this problem is discussed in Section 4 and the variables involved in this study have previously been used and analyzed (Ruiz-Padillo et al., 2014).

Finally, the information derived from the expert panel was statistically analyzed using a linear model for the analysis of variance (ANOVA), using Tukey's test, to compare and test the consistency of the results.

3.2. Social choice functions

Responses from an expert panel can be regarded as voting results. In this way, some scoring voting methods through SCF were implemented, which use the EPT's results in order to achieve a ranking that reflects the views of all the experts in an objective and plural manner. The SCFs used in this study were Plurality, Raynaud, Kemeny-Young, Copeland, Simpson, Schulze, and Borda, because they are either popular or adequate to our problem.

Plurality, Schulze, and Simpson methods provide only single-winner results among the candidates but do not yield a complete ranking. Since the aim of this work is to achieve a complete list of variables sorted by priority, such SCFs were adapted in order to be able to rank all candidates from the highest to lowest score. Moreover, in their original formulation, some SCFs are not able to break ties. Therefore, further criteria to establish prevalence among those tied candidates were also defined.

In short, SCFs take the candidates ordered by experts' preferences as input and then return the chosen candidates or a ranking of them. In the present research, the relationship of preference is strict, because the experts' questionnaire answers did not allow “ties” between the variables when sorting them by importance.

In applying voting methods in expert panel results, it is useful to construct a special ranking-schedule table (ranking matrix), with the following properties: The size of the matrix is $m \times n$, where m is the number of voters (participants in the expert panel) and n is the number of candidates (the RSPV). Thus, each row represents the ranking of the RSPV performed by one expert. If o_j is the best variable for the i-th voter, then the rank number is $r_{ij} = 1$; if o_j is the second best candidate, then $r_{ij} = 2$, and so on. If variable o_j is the worst one, then $r_{ij} = n$. In this way, each row of the ranking table is simply a permutation of the integers 1, 2, …, n (Srdjevic, 2007).

Similarly, two other useful matrices can be defined for applying the different SCFs selected, these coming from the ranking matrix (Alcantud et al., 2013; Green-Armytage, 2004; Srdjevic, 2007):

1. Comparison matrix: this is a $n \times n$ matrix, in which each element c_{ij} represents the number of times that voters estimated variable o_i to be more important than variable o_j. With respect to the definition of the data obtained from the experts, ties were not possible, and hence it could be verified that $c_{ii} = 0$, for all $i = 1, \ldots, n$; and $c_{ji} = m - c_{ij}$, for all i different from j.
2. Preference matrix: this is also a $n \times n$ matrix, which represents the absolute victories of one variable on another for all voters. Thus, each element p_{ij} is:
   - $p_{ij} = 1$, if variable o_i was ranked in a higher position than a variable o_j most of the time;
   - $p_{ij} = -1$, if variable o_j was ranked in a higher position than a variable o_i most of the time; and
   - $p_{ij} = 0$, otherwise, i.e., if $i = j$ (elements of the main diagonal), and if both variables received the same number of votes on each other (as mentioned, in the present case this was not possible because there were no ties in the experts' rankings and there was an odd number of voters).

Due to the special population and responses characteristics of the expert panel, the preference matrix is antisymmetric, i.e., $p_{ij} = -p_{ji}$. This matrix can be easily derived from the previous one, because if $c_{ij} > m/2$, then $p_{ij} = 1$; if $c_{ij} = m/2$, then $p_{ij} = 0$ (not possible in the present case); if $c_{ij} < m/2$, $p_{ij} = -1$; and $p_{ii} = 0$, for all $i = 1, \ldots, n$.

The ranking resulting from the application of SCF is denoted as $\{v_k\}$, $k = 1, \ldots, n$.

An extensive revision of the definition of the SCF can be accessed in Green-Armytage (2004). The selection of methods and their adaptations are presented in the following subsections. The methods were adapted to manage this specific problem, with the aim of looking for a strict ranking of variables and for dealing with our type of data.

3.2.1. SCF implemented using a Python library

In this research, *BallotBox* (https://pypi.python.org/pypi/ballotbox/0.1), a Python library that implements some voting methods, was chosen. The complete list of methods can be found on (http://pythonhosted.org/ballotbox/docs/methods/VOTINGMETHODS.html). This library takes a list containing each of the experts' ranking as input. These methods are based on a complete ordering of the variables. Below, the main ideas of these methods are discussed, with special emphasis in the application to the problem in the present work.

3.2.1.1. Borda Count voting method. The Borda Count voting method uses a ranking of preferences. This ordering assigns points to each candidate: for n candidates, it contributes $n - 1$ points to the highest ranked candidate, $n - 2$ points to the second highest ranked one, and so on. It assigns no points to the lowest ranked candidate. Thus, for each r_{ij} in the ranking matrix, a number $q_{ij} = n - r_{ij} + 1$ is assigned by the above procedure, and the total

score for variable j is given as in Eq. (2).

$$Q_j = \sum_{i=1}^{m} q_{ij} = m \cdot (n-1) - \sum_{i=1}^{m} r_{ij} \quad (2)$$

The winner of the social choice is the one for which the total sum of points from all the voters is maximal, i.e., the variable with the highest Q value ($Q_j^* = max\ Q_j$). A complete ordering is possible according to the Q values.

BordaVoting is *BallotBox*'s implementation of the Borda Count voting method. This method outputs a list of tuples containing both the ranked variables and the sum of the points received by each one.

3.2.1.2. Kemeny-Young voting method. Another SCF implemented using the Python library was the Kemeny-Young voting method. This method evaluates each ordering of the candidates in terms of the sum of preference reversals on each ranking that would have to be performed in order to produce that transitive ordering. The minimum number of reversals necessary to transform a given ordering into another one determines the concept of the Kendall distance between two permutations or orderings. The complete ranking that requires the fewest preference reversals is the final result of the method and is called the "Kemeny consensus" (Kemeny, 1959; Levenglick, 1975). Therefore, the method seeks to minimize the total number of disagreements between the input orderings and the optimal ordered list.

Thus, for the m rankings provided by the m experts (voters) on a set O of n variables (candidates), the preference profile Λ consists of m rankings (orders) $\lambda = \{a_1 \succ a_2 \ldots a_s \succ a_t \ldots a_n\}$, where each may include a strict preference relation $\succ$. The ranking λ can be represented by the ranking matrix R, rows and columns of which are labeled by the variables' numbers and $r_{ij} = 1$ if $o_i \succ o_j$ or $r_{ij} = -1$ if $o_i \prec o_j$. Then the symmetric difference distance function between two rankings λ_k and λ_l is defined by Eq. (3), where only the elements of the upper triangle submatrix, r_{ij}, $i < j$, are added together.

$$d(\lambda_k, \lambda_l) = \sum_{i<j} \left| r_{ij}^k - r_{ij}^l \right| \quad (3)$$

Then, a distance between an arbitrary ranking λ and the profile Λ can be defined as in Eq. (4), where *pij* are the elements of the so-called profile matrix *P*.

$$D(\lambda, \Lambda) = \sum_{k=1}^{m} d(\lambda, \lambda_k) = \sum_{i<j} \sum_{k=1}^{m} \left| r_{ij}^k - r_{ij} \right| = \sum_{i<j} \sum_{k=1}^{m} d_{ij} = \sum_{i<j} p_{ij} \quad (4)$$

Each permutation of variables of O corresponds to the transposition of the rows and columns of the rankings matrix. Hence, the Kemeny-Young method seeks the determination of such a transposition of profile matrix rows and columns such that the sum of elements of its upper triangle submatrix is minimal.

The characteristic parameter of matrix P is a least distance D_{least} from its preference profile Λ to any linear order. The parameter is calculated by summing up lower elements of each pair (p_{ij}, p_{ji}), as in Eq. (5).

$$D_{least} = \sum_{i<j} \min\left(p_{ij}, p_{ji}\right) \quad (5)$$

KemenyYoungVoting implements the Kemeny Young voting method from the *BallotBox* library. It is important to note that for this method to work with our data, the original *BallotBox* code was slightly changed. This change was made in order to be able to execute the Kemeny-Young method as presented in Fig. 1. With this change, the code "snippet" could be executed, as depicted in Fig. 2. As a result, the ranking of candidates after applying the Kemeny-Young method is printed.

This computation is the most expensive of the SCFs used in this paper because this method requires the analysis of the *n!* possible rankings for calculating and determining of the minimal D_{least}. Thus, the computational complexity of the Kemeny-Young method is exponential with respect to the number of variables. Given that we are dealing with only nine variables, in this case this is a minor issue but it could be relevant in other environmental problems.

3.2.2. SCF implemented in R software

Only some of the SCF selected for using in this paper were available in the *BallotBox* Python library. Thus, the following methods and their adaptations were implemented using R, an integrated, well developed, simple and effective suite software for data manipulation, calculation and statistical computing (R, 2015). This programming language was chosen due to its easy implementation of data analysis algorithms. In addition, R environment provides a useful data handling, storage facility, a suite of operators for calculations on matrices, and a large, coherent, integrated collection of intermediate tools for data analysis.

3.2.2.1. Plurality voting method. Plurality is the most common and intuitive single winner method used. The plurality method simply gives the victory to the candidate receiving the most votes (a plurality). This concept can be mathematically formulated as follows:

Define $p(r_{ij}) = 1$ for $r_{ij} = 1$, and $p(r_{ij}) = 0$ otherwise. If for each variable o_j the sum $P_j = \sum_{i=1}^{m} p(r_{ij})$ is computed, then the number P_j simply indicates how many times candidate o_j has been ranked as the best. The variable with the largest P_j value is considered the social choice; i.e. $v_1 = o_j, j/P_j = max\ \{P_k\}, k = 1, \ldots, n$.

In the present case, as a means of generating a ranking for the RSPV, the following adaptation of the Plurality method was made (Fig. 3): once the winning candidate is found, it is removed from the rankings of the experts and the P_j indicator is recalculated for the remaining variables. Thus, the candidate with the highest P_j value is located in the second place in the ranking. The process continues until all candidates are sorted from highest to lowest rank. The P indicator of the previous iteration was used to rank the tied candidates, and so on until the tie is broken.

3.2.2.2. Copeland method. Another method implemented in R was Copeland's, which assigns the winner by the strict simple-majority rule (see Fig. 4). Copeland's method is a variant of the Condorcet method in which the candidates are ranked on the basis of a score calculated by subtracting the pairwise losses from their victories. The higher the score, the better the position in the final ranking. Thus, the Copeland score of a candidate is the difference between the number of candidates that it defeats and the number of candidates by which it is defeated. This is further detailed as follows:

Compare candidate o_i with every other candidate o_j. Assign +1 if the majority prefers o_i to o_j, −1 if the majority prefers o_j to o_i, and 0 if there is a tie. Adding together those scores over all o_j distinct from o_i yields the Copeland score of o_i. All candidates can be sorted according to their score.

The Copeland score values can be easily calculated from the preference matrix, simply by adding together the elements of each row:

$$S_j = \sum_{i=1}^{n} p_{ij}, j = 1, 2, \ldots, n \quad (6)$$

In case of ties, they are broken according to the pairwise

```
85  def get_ranks(self):
86          ranks = []
87          for possibility in itertools.permutations (self.preference_options):
88                  rank = 0
89                  for index, option 1 in enumerate (possibility[:− 1]):
90                          for option2 in possibility[index + 1:]:
91                                  key = ”%s > %s” % (option1, option2)
92                                  if key in self.lookup:
93                                          rank += self.lookup[key]
94                  ranks.append ((rank, possibility))
95          return sorted(ranks, reverse=True)
```

Fig. 1. *BallotBox* change for Kemeny-Young voting method.

```
from ballotbox.singlewinner.preferential import KemenyYoungVoting
kemeny = BallotBox(method =KemenyYoungVoting)
for ranking in votes:
        kemeny.add_votes(ranking, 1)
result = kemeny.get_winner()[0]
for candidate in result[1]:
print(candidate)
```

Fig. 2. *BallotBox* Kemeny-Young code snippet.

```
INPUT list_of_candidates, votes
OUTPUT ranking
for every position in the ranking:
    for each variable not already selected:
        count the number of votes on the position
    choose the variable not already selected that has the most votes
return ranking
```

Fig. 3. Plurality method pseudocode implemented in R.

relationship of the tied candidates.

3.2.2.3. Raynaud method. In the Raynaud method, the candidate with the strongest pairwise defeat among the remaining candidates is eliminated until only one remains. When a candidate is eliminated, the pairwise comparisons between that candidate and the other are also removed, and hence a strong defeat by that candidate will not matter to any candidate left after the elimination. When multiple candidates share defeats of equal magnitude, only one of the candidates is eliminated in each iteration. Therefore, different classifications are assigned for the candidates that should share the same positions.

The Raynaud method takes into account the intensity of defeats (see Fig. 5). Rows and columns in the comparison matrix corresponding to the eliminated candidates are extracted until only one remains. Therefore, the ranking is generated in reverse order, from the least significant variables to the winner. However, it is common to find ties in the final ranking, corresponding to the variables that are removed together at each step.

To find a strict ranking, the adaptation of the method used in this work sought to eliminate only one candidate each time. Thus, in case of ties, only one candidate was selected from among the variables that shared the strongest defeat. For each of these tied variables the next strongest pairwise defeat was addressed, and so on until the tie was removed. Only the candidate that collected the strongest defeats within the group selected by the original method was extracted. The other candidates continued into the next round, and the process was repeated. This unique sequential removal allowed us to generate a complete reverse ranking in an easier way and avoid a large number of ties.

3.2.2.4. Schulze method (or beatpath method). In the Schulze method, pairwise competitions are extended through the use of intermediate victories, using the idea of “transitive defeat”. A “transitive defeat” (also known as a chain) allows A to beat C through a chain of comparisons, such as $A > B$ and $B > C$. Even if C defeats A in a head-to-head comparison, if a chain from A to C exists, then A can “transitively defeat” C. A chain is only as strong as its weakest link. The strength of a chain from A to C is measured by the smallest margin of victory between any two alternatives in the

```
INPUT list_of_candidates, votes
OUTPUT ranking
losses = vector(number_of_candidates)
wins = vector(number_of_candidates)
for each pair of candidates:
    candidate_A_wins = 0
    candidate_B_wins = 0
    for each vote:
        if candidate A is at a better position:
            candidate_A_wins += 1
        if candidate B is at a better position:
            candidate_B_wins += 1
    if candidate_A_wins > candidate_B_wins:
        wins[candidate_A] += 1
        losses[candidate_B] += 1
net_wins = wins - losses
//orders the candidates according to their net wins
ranking = order(net_wins, candidates)
return ranking
```

Fig. 4. Copeland method pseudocode implemented in R.

```
INPUT list_of_candidates, votes
OUTPUT ranking
//calculates pairwise matrix
pairwise_matrix = calculate_pairwise_matrix(votes, list_of_candidates)
for each pair (A,B) of candidates:
    matrix[A,B] = number of votes where A wins over B
    matrix[B,A] = number of votes where B wins over A
while pairwise_matrix is not empty:
    choose candidate C with the worst defeat
    remove the row and column of C from the pairwise_matrix
    add C to the top of the ranking
return ranking
```

Fig. 5. Raynaud method pseudocode implemented in R.

chain. In other words, if candidate *A* defeats *B* and *B* defeats *C*, then *A* defeats *C* with an intensity equal to the weakest defeat. The aim is to find an alternative with the strongest chains through which it can defeat all other alternatives. Thus, if *A* has a stronger path than *B*, then *A* defeats *B*. If both candidates are equally strong, then there is a tie between *A* and *B*. This ordering by victories is used to calculate the final ranking of the candidates. The method is equivalent to a method in which we sequentially measure the strength of the candidates and then remove the weak ones, and then re-evaluate.

The method can be easily implemented from the preference matrix, simply by adding the elements of each row (Fig. 6). If there are ties, they can be removed according to the result of a strict comparison between each pair of tied candidates in the matrix used. Thus, a complete relative ranking can be established among them.

3.2.2.5. Simpson method (or minimax method). The Simpson method determines the winner as the candidate whose worst pairwise defeat is better than the rest of the candidates. Such worst defeats can be established from the comparison matrix. An adaptation of the Simpson method was implemented to establish complete rankings (see Fig. 7). This was based on the comparison of the worst defeats of each candidate and sorting the variables according to them, in decreasing order. For the ties that frequently arose, the next worst defeats between the tied candidates were compared, and the process continued until all the ties are broken.

4. Results and discussion

4.1. Development of the expert panel

In this study, great importance was given to the composition

```
INPUT list_of_candidates, votes
OUTPUT ranking
//calculates pairwise matrix
pairwise_matrix = calculate_pairwise_matrix(votes, list_of_candidates)
path_matrix = matrix(num_of_candidates, num_of_candidates)
for every pair (A,B) of candidates:
    if(pairwise_matrix[A,B] > pairwise_matrix[B,A]):
        path_matrix[A,B] = pairwise_matrix[B,A]
    else
        path_matrix[A,B]=0
    if(pairwise_matrix[B,A] > pairwise_matrix[A,B]):
        path_matrix[B,A] = pairwise_matrix[A,B]
    else
        path_matrix[B,A]=0
for every candidate A:
    for every candidate B:
        for every candidate C:
            if(A!=B and C!=A and C!=B)
        path_matrix[B,C] =
        max(path_matrix[B,C],min(path_matrix[B,A],path_matrix[A,C]))
//based on the path matrix information
//search for the ordering of candidates
//with the strongest beatpath
ranking = get_strongest_beatpath(path_matrix)
return ranking
```

Fig. 6. Schulze method pseudocode implemented in R.

```
INPUT list_of_candidates, votes
OUTPUT ranking
//calculates pairwise matrix
pairwise_matrix = calculate_pairwise_matrix(votes, list_of_candidates)
ranking = vector()
while there are variables not yet selected:
    new_pairwise_matrix = remove_selected_candidates(pairwise_matrix, ranking)
    //get the candidate(s) with the worst pairwise
    worst_loss = min(new_pairwise_matrix)
    worst_candidates = calculate_worst_candidates(new_pairwise_matrix)
    //a tie can happen. In this case, use the next worst defeats until the tie is broken
    levels_searched = 1
    while(length(worst_candidates) > 1):
        temp_pairwise_matrix = new_pairwise_matrix
        worst_loss = min(new_pairwise_matrix)
        worst_candidates = calculate_worst_candidates(new_pairwise_matrix)
        levels_searched += 1
    ranking.add(worst_candidates[1])
return ranking
```

Fig. 7. Simpson method pseudocode implemented in R.

and size of the members for the EPT employed with the intention of ensuring valid and unbiased results. Therefore, technicians of the highest hierarchical level of the departments responsible for roads in the three different administrative categories in the autonomous region of Andalusia, southern Spain, were consulted.

Andalusian administrative structure is divided into eight provinces, and both the Central Government and the Regional and Provincial Governments have one technician chief leading every road department in each province, i.e. a total of 24 managers. Additionally, the Regional Administration has a central road department in the capital city of the Autonomous Region, with a steering group composed of five heads of service. Since they are the small number of people with management responsibilities in the problem addressed here, only these group satisfies the specific characteristics required for being members of the expert panel in our study.

As a result, 24 experts were selected (almost the entire population involved in the decision-making process coming from all provinces in the region of Andalusia, southern Spain) and of these, 19 experts returned their filled-out questionnaires. This ratio means a very high degree of success (79%), which gave a great representativeness to the results. Also, the number of panel participants was adequate, according to the current literature, and all the provinces and administrative levels were fully represented in the data acquisition process.

The nine RSPV (see Table 1) were submitted to the experts after a brief explanation about its meaning and about the adopted notation in the survey. Then, with some instructions about the questionnaire, they were asked to sort the variables according to their relative importance in the decision-making problem of sorting road stretches by priority for action against traffic noise. In particular, the question was:

Please sort by importance from 1 to 9 (being 1 the most important and 9 the least important) each of the following variables in relation to the problem of setting priorities for action to the road stretches with traffic noise problems, regardless of the value of each indicator and of the financial resources available to address the problem.

With this purpose, each expert wrote in the questionnaire the degree of influence (1–9, from more to less importance) that he/she estimated for the RSPV.

Then, one more question was presented to the experts: *In addition to the variables mentioned above, do you think that it is necessary to consider some other variable in the problem of establishing priorities for action to the road stretches with traffic noise problems? If so, which ones?*

In this case, experts must fill in the appropriate field of the survey with the additional variables and indicators. This procedure ensured the convenience and quality of the considered RSPV, and it made necessary to add in the list the vehicle speed parameter.

The experts' rankings of the nine RSPV, obtained from their answers, are presented in Table 2.

Tukey's test was then applied to the data obtained from the expert panel (Table 2), showing (at a confidence level of 95%), that the means of the RSPV were comparable in four different groups, following the order: (i) $P_{exp} - CS_{exp}$; (ii) $\Delta L - ADT - E_C$; (iii) $E_{ANM} - \%hv$; and (iv) $s - S_{exp}$.

4.2. Outcomes from social choice functions

The orderings given by the experts as answers to the questionnaires (see Table 2) enabled the construction of the ranking matrix. Subsequently, the comparison and preference matrices (Tables 3 and 4) were generated from experts' voting, as explained in Section 3.2. These matrices are the input for the SCF used in this work, according to the procedures described in Sections 3.2.1 and 3.2.2.

Table 2
Data from expert panel.

Experts	Rankings								
	1	2	3	4	5	6	7	8	9
E1	ΔL	SC_{exp}	P_{exp}	S_{exp}	E_{ANM}	ADT	$\%hv$	s	E_C
E2	P_{exp}	ADT	ΔL	SC_{exp}	E_{ANM}	E_C	s	$\%hv$	S_{exp}
E3	P_{exp}	SC_{exp}	E_C	ΔL	$\%hv$	ADT	s	S_{exp}	E_{ANM}
E4	ADT	P_{exp}	SC_{exp}	S_{exp}	E_C	ΔL	$\%hv$	E_{ANM}	s
E5	SC_{exp}	P_{exp}	E_C	ΔL	S_{exp}	E_{ANM}	ADT	$\%hv$	s
E6	P_{exp}	SC_{exp}	ΔL	S_{exp}	ADT	s	E_C	E_{ANM}	$\%hv$
E7	E_C	SC_{exp}	P_{exp}	ΔL	ADT	s	$\%hv$	S_{exp}	E_{ANM}
E8	P_{exp}	ADT	ΔL	E_C	SC_{exp}	E_{ANM}	$\%hv$	s	S_{exp}
E9	SC_{exp}	P_{exp}	E_C	ΔL	ADT	$\%hv$	s	S_{exp}	E_{ANM}
E10	P_{exp}	SC_{exp}	E_{ANM}	ΔL	E_C	$\%hv$	ADT	s	S_{exp}
E11	P_{exp}	SC_{exp}	ADT	E_C	E_{ANM}	$\%hv$	s	ΔL	S_{exp}
E12	SC_{exp}	P_{exp}	ADT	$\%hv$	S_{exp}	ΔL	E_{ANM}	s	E_C
E13	ADT	SC_{exp}	E_C	P_{exp}	ΔL	E_{ANM}	s	$\%hv$	S_{exp}
E14	P_{exp}	SC_{exp}	ΔL	E_C	ADT	$\%hv$	E_{ANM}	s	S_{exp}
E15	P_{exp}	ΔL	SC_{exp}	ADT	E_C	S_{exp}	$\%hv$	s	E_{ANM}
E16	P_{exp}	ΔL	ADT	$\%hv$	s	SC_{exp}	E_C	E_{ANM}	S_{exp}
E17	ΔL	SC_{exp}	E_{ANM}	P_{exp}	ADT	s	$\%hv$	E_C	S_{exp}
E18	ΔL	P_{exp}	ADT	S_{exp}	SC_{exp}	E_C	E_{ANM}	s	$\%hv$
E19	ΔL	P_{exp}	SC_{exp}	E_C	ADT	s	$\%hv$	E_{ANM}	S_{exp}

The SCFs applied in this paper generated ranked lists presented in Table 5. These results indicate that there were very noticeable matches between the rankings obtained by the different SCFs in the top positions. This finding is remarkable, since the methodology applied gives clear results. In fact, it is noteworthy that the top five positions matched in all the ordered lists: the highest importance was given to the variables P_{exp}, SC_{exp}, ΔL, ADT, and E_C.

An analysis of the findings gives the following results. The variables that take into account the exposure parameters of greater effect on the citizens (P_{exp} and SC_{exp}) received the utmost importance of the RSPV as criteria for prioritizing the road stretches with noise problems due to the traffic. Following this ranking and with the ordering by the SCF, the next three variables indicated the importance given to the intensity of the problem, measured directly by ΔL, ADT and E_C, respectively: that is, the degree of breach of current legislations (the necessary attenuation or difference between the existing noise level and the acoustic quality objective required by the regulations), the traffic volume (one of the main parameters that influence the noise generation on roads), and the direct demonstration of the citizens about the existing noise problem through their complaints to the competent administration.

In the remaining positions, the experts also agreed on the least important criteria to prioritize necessary actions against traffic noise in a set of road stretches. For instance, $\%hv$ variable appeared mainly in the sixth or eighth positions, while E_{ANM} parameter varied from sixth to seventh positions. In some cases, the same importance was given to the percentage of heavy vehicles, $\%hv$

Table 3
RSPV comparison matrix.

	ΔL	P_{exp}	S_{exp}	ADT	$\%hv$	s	E_C	SC_{exp}	E_{ANM}
ΔL	0	4	17	13	17	18	12	8	17
P_{exp}	15	0	19	17	19	19	17	12	18
S_{exp}	2	0	0	3	6	7	5	1	10
ADT	6	2	16	0	17	19	12	6	15
$\%hv$	2	0	13	2	0	12	4	1	9
s	1	0	12	0	7	0	5	1	7
E_C	7	2	14	7	15	14	0	2	14
SC_{exp}	11	7	18	13	18	18	17	0	19
E_{ANM}	2	1	9	4	10	12	5	0	0

Table 4
RSPV preference matrix.

	ΔL	P_{exp}	S_{exp}	ADT	$\%hv$	s	E_C	SC_{exp}	E_{ANM}
ΔL	0	−1	1	1	1	1	1	−1	1
P_{exp}	1	0	1	1	1	1	1	1	1
S_{exp}	−1	−1	0	−1	−1	−1	−1	−1	1
ADT	−1	−1	1	0	1	1	1	−1	1
$\%hv$	−1	−1	1	−1	0	1	−1	−1	−1
s	−1	−1	1	−1	−1	0	−1	−1	−1
E_C	−1	−1	1	−1	1	1	0	−1	1
SC_{exp}	1	−1	1	1	1	1	1	0	1
E_{ANM}	−1	−1	−1	−1	1	1	−1	−1	0

Table 5
Ranking positions from applying SCF to data.

SCF	Ranking positions								
	1	2	3	4	5	6	7	8	9
Plurality	P_{exp}	SC_{exp}	ΔL	ADT	E_C	S_{exp}	E_{ANM}	$\%hv$	s
Borda Count	P_{exp}	SC_{exp}	ΔL	ADT	E_C	$\%hv = E_{ANM}$		S_{exp}	s
Copeland	P_{exp}	SC_{exp}	ΔL	ADT	E_C	E_{ANM}	$\%hv$	s	S_{exp}
Kemeny-Young	P_{exp}	SC_{exp}	ΔL	ADT	E_C	$\%hv$	E_{ANM}	s	S_{exp}
Raynaud	P_{exp}	SC_{exp}	ΔL	ADT	E_C	E_{ANM}	S_{exp}	$\%hv$	s
Schulze	P_{exp}	SC_{exp}	ΔL	ADT	E_C	$\%hv = E_{ANM}$		S_{exp}	s
Simpson	P_{exp}	SC_{exp}	ΔL	ADT	E_C	E_{ANM}	S_{exp}	$\%hv$	s

(parameter characterizing traffic with widespread influence on noise-map generation as well as on the population's noise perception), and the existence or pre-planning of any other anti-noise measure in the road stretch, E_{ANM}. Secondly, the parameter of the average speed of vehicles (s) appeared in the eighth or ninth positions, often swapping positions with the S_{exp} variable. It should be recalled that the S_{exp} variable measures the noise effect on the area adjacent to the infrastructure, but it does not take into account whether the surface is inhabited or noise exposure is really affecting the population. Additionally, it must be taken into account the later incorporation of the s variable in the RSPV list, so its small relative importance in the problem is coherent.

As can be deduced from these results, the "average" consensus ranking that could be proposed for the RSPV from the SCF results was the following: P_{exp}, SC_{exp}, ΔL, ADT, E_C, and $\%hv$, E_{ANM}, $S_{exp,}$ and s. The similarity of the results of the SCF, regardless the specific SCF used, gives consistency to this approach. These outcomes are also consistent with the results of Tukey's test mentioned in Section 4.1. Accordingly, the applicability and appropriateness of the ranking resulting from the use of the SCF were verified for the selection of variables to prioritize actions against road traffic noise made in real study cases (Ruiz-Padillo et al., 2014) based only on expert knowledge without this tool.

5. Conclusions

The relative importance of the main variables influencing the process of prioritizing road stretches for action against traffic noise (identified previously as nine Road Stretch Priority Variables, RSPV) was successfully evaluated by the expert panel technique (EPT). Additionally, the specialists' opinions determined from EPT were aggregated by seven social choice functions (SCF): Plurality, Raynaud, Kemeny-Young, Copeland, Simpson, Schulze, and Borda. With this aim, the data compiled was assimilated to the results of a voting process on nine candidates. Some of the selected SCF offer only the winning candidate as a result, so they needed to be adapted in order to provide a complete ranking of the variables and in some cases, some changes were made to deal with this problem. Then, the SCF were appropriately implemented by a Python library and programming in R software.

A consensus ranking from the SCF results was achieved, with two clearly differentiated groups of variables: a leading group with the two variables that take into account the population and noise-sensitive centers exposed to road traffic noise; followed by variables measuring the necessary noise attenuation, the traffic volume, and the existence of complaints about noise in relation to the road stretch studied; and, finally, the remaining variables as the least-significant criteria, all four at very similar importance levels. These results also agree with a statistical analysis of variance (ANOVA) for multiple comparisons (Tukey's test), so that the use of SCF strengthens other possible rankings, gaining a deeper insight into the process and reinforcing the goodness of the ranking performed. Moreover, the consensus ranking achieved was reasonable from the standpoint of the significance of the variables in the decision problem analysis.

In summary, the combination of EPT and SCF used in this study proved highly suitable for the data processing and for the variable selection and ranking to prioritize actions against road traffic noise. Once the ranking of the variables is established, the decision maker can use them within any multicriteria decision techniques, in order to sort road stretches for priority of action against noise within the Noise Action Plan. In this context, future research will be conducted to specify the relative importance and influence of the variables in the decision problem by defining weights for use in drafting the Noise Action Plan. The achieved consensus ranking for the RSPV becomes a very appropriate starting point for the weighting process. Also, this methodology can also be easily implemented or extended to further phases of the decision methodology and to other real decision problems.

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